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THINNING PONDEROSA PINE IN THE SOUTHWEST

By Edward M. Gaines and E. S. Kotok

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Cover picture: Fort Valley Experimental Forest Section 19 thinning plot 4; 160 banded crop trees per acre were given heavy release in 1936 and were making fair growth in 1947 when photo was taken. Total basal area was 154 sq. ft. per acre in 1947, and a cordwood market would have permitted uniform commercial thinning to 80 sq. ft., largely in the original crop trees. Some non-crop trees could now be removed for poles, if market were available.

THINNING PONDEROSA PINE IN THE SOUTHWEST

By
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INTRODUCTION

Proper thinning of overdense young stands of ponderosa pine will increase the growth rate on reserved trees and thereby reduce the time required to grow the stands to rotation size. A shortened rotation has a positive value. A stand at final rotation size will presumably yield the same volume regardless of its age, and if the volume is grown in a shorter time, the average annual yield is increased.

The true value of a shortened rotation has not been appreciated heretofore. The fact that total cubic-volume growth seldom increases during the first years following thinning has led to the erroneous conclusion that thinning doesn't pay. The potential long-term gain has been discounted or overlooked entirely.

Two recent developments prompt a new look at the question of thinning in the southwestern region (Arizona and New Mexico). The promise that lumber and stumpage prices may be maintained at a relatively

1/ Acknowledgment is made to George S. Meagher of the Pacific Northwest Forest and Range Experiment Station (formerly of the Southwestern Station) for preliminary work and analyses which guided this study.
2/ Forest Service, U. S. Department of Agriculture, with headquarters at Colorado A & M College, Fort Collins, Colorado.

high level encourages a general intensification of forest-management practices; and the current development of the first real market for cordwood-sized trees, with the hope that such markets may become common in the years just ahead, provides an immediate need for a reconsideration of guides to thinning practices. For there can be no question that a proper thinning that pays its own way is desirable silviculturally.

HISTORY OF THINNING STUDIES

Scattered throughout the southwestern region are dense stands of young ponderosa pine dating back to cuttings as early as the 1880's. An abundant 1919 reproduction crop emphasized the need for information in managing densely stocked juvenile stands, and in 1925, the first of a series of thinning studies was started on the Prescott National Forest in north-central Arizona, followed by other similar studies on the Fort Valley Experimental Forest and the Sitgreaves National Forest in Arizona, and on the Gila National Forest in New Mexico. Tentative guides for the management of young stands can now be developed from the data and observations from these areas.

Table 1 gives a general description of the study areas. With the exception of the Corey pasture and the Fort Valley section 19 plots where crop trees only were released, initial thinning was done on a uniform-spacing basis. It was only in the 12-year-old Decker Wash and one of the 20-year-old Corey pasture sapling-sized stands, however, that a relatively large number of stems was removed.

Thinning remained an academic subject until the CCC and other emergency work programs of 1933 made it possible to test thinning theories in practice. Initial thinnings followed the concept of uniform thinnings, but in 1934 uniform thinnings were abandoned in favor of the "crop-tree" method. In this method, trees of good form and of good promise (thrifty dominants and codominants) were selected and released if necessary to maintain or accelerate growth. The crop-tree method was favored because it was considerably cheaper than uniform thinning and also because it would presumably develop greater differential dominance in a stand and thus convert the forest more towards a selection type.

The crop-tree method, as used during the CCC period, was described by Pearson (9).3/ Sixty to 120 trees per acre were to be selected. Little or no release was prescribed if the selected crop tree was distinctly dominant; otherwise the crown of the crop tree was to be freed on at least three sides. It now appears that greater release is desirable to develop optimum growth of crop trees.

REVIEW OF PUBLISHED RESULTS

In the first report on a southwestern thinning study, Pearson (8) showed that the thinned White Spar plots made somewhat more basal-area

3/ Numbers in parentheses refer to Literature Cited, page 20.

Table 1.-- Descriptive summary of thinning studies

National forest and location	Date established	No. of plots	Range in plot size (Acres)	Elevation in feet, and soil type	Age of stand at establishment (Years)	Date of latest measurement	No. of test plots	No. of check plots
Coconino								
Ft.Valley "Ranger"	June 1927	7	0.043 0.154	7,600 malpais	35	Oct. 1946	5	2
Ft.Valley "Sec.19"	May 1936 Aug.1936[1/]	8	0.269 0.500	7,600 malpais	40	June 1947	6	2
Ft.Valley "Corey pasture"	Sept.1934	4	0.115	7,350 malpais	20	Oct. 1947	3	1
Gila Redstone	Sept.1933	16	0.100 0.250	7,300 malpais	30-40	Oct. 1948	14	2
Prescott								
Copper Basin	Oct. 1933	3	0.600	6,400 granitic	30-60	Sept.1948	2	1
White Spar	Sept.1925[2/]	4(5)	0.240 2.100	5,500 granitic	40	Oct.1946	3	2
Sitgreaves								
Decker Wash	May 1926 Oct.1926 (5th plot)	5	0.115 0.143	7,000 gravelly silt loam	12	May 1948	4	1

1/ Check plots established 1936 after growing season.
2/ Plots A, B, and C established in 1925, Plot D in October 1930, and A subdivided into A-1 and A-2 in October 1935.

increment during the first 10 years after treatment than did the unthinned plots. The most significant effect of thinning was that selected "final crop" trees on thinned areas grew 0.45 inch (62 percent) greater in diameter than similarly selected trees on unthinned areas during the decade. Thus, stand increment was concentrated on fewer stems which would, in effect, reduce the rotation age of the stand.

Krauch (4), in reporting on the second decade of growth on these same plots, found little difference in basal-area growth between thinned and unthinned plots. Height growth was slightly better on the thinned plots. Diameter growth of selected trees averaged 0.34 inch greater on thinned than on unthinned areas, indicating that the effects of release were diminishing as total basal areas increased. He speculated, however, that thinning might reduce the total time needed to each a 20-inch d.b.h. rotation size by as much as 30 years.

Hornibrook (2), in his analysis of the Fort Valley "Ranger" plots, showed that the mean diameter increment of 80 selected trees per acre on plots thinned to wide spacing was greater than increment on the same number of trees selected on plots of close spacing or on unthinned control plots.

Krauch (3) found that 5 years' results on the Gila thinning plots were in accord with earlier findings on the White Spar and Fort Valley "Ranger" plots. Dominants, in general, were able to maintain their diameter-growth rate in unthinned stands although a slightly faster growth of the larger stems in thinned stands was observed.

Only a brief report (10) has been made on the Decker Wash plots, the earliest study of thinning in very young stands. Moderately thinned stands had somewhat taller trees at age 27 than did unthinned, lightly thinned, or very heavily thinned stands. Tip-moth damage was evident on all plots, but appeared most active in the heavily thinned stands.

MORE RECENT RESULTS

Thinning in Pole-Sized Stands

In general, past reports have shown that little or no increase in basal-area or volume growth per acre can be expected as a result of thinnings, but that individual trees, especially selected crop trees, grow faster when released. More recent data confirm and strengthen this previous conclusion.

The Section 19 plots, which were originally set up on the crop-tree basis, demonstrate these premises clearly. Crop trees were selected at rates of 80, 120, and 160 per acre on paired plots, and one plot of each pair was given heavy release and one light release. Two unthinned plots were established and 160 of the best trees per acre were designated as potential crop trees.

After 11 years, the study showed little difference in total basal-area growth, but a definite relationship between crop-tree diameter growth and the intensity of release for each pair of plots. Heavy release showed an advantage of 10 to 37 percent over light release, in terms of diameter growth, and light release was 30 percent better than no release. A slight advantage in height growth was of doubtful significance. As would be expected, 80 trees per acre made a better showing than did 120 or 160, simply because fewer, and therefore better, trees were selected. Table 2 summarizes diameter- and height-growth data from each of 6 treated plots and the average of 2 untreated check plots.

Most of the originally chosen crop trees still appear to be the best growing specimens, 18 years after their selection. Apparently selection can be made with reasonable assurance of future development. Such unpredictable factors as porcupines, insects, and snow damage were responsible for decline of a few crop trees.

Table 2.--Average annual diameter and height growth for crop trees, Fort Valley Section 19, average of 11 years

Crop trees per acre	Average annual diameter growth			Average annual height growth		
	Heavy release	Light release	No release	Heavy release	Light release	No release
No.	In.	In.	In.	Ft.	Ft.	Ft.
80	0.173	0.126	--	0.725	0.734	--
120	.123	.111	--	.653	.603	--
160	.126	.103	0.079	.744	.633	0.605

The Fort Valley Ranger plots were thinned uniformly, but shortly later 160 of the best trees per acre were selected and designated as crop trees. Measurements 20 years after thinning, summarized in table 3, showed that crop trees on thinned plots had, with one exception, grown 10 to 33 percent faster in diameter than those on unthinned check plots. Diameter growth was inversely related to residual basal area, the fastest growth occurring on the plot with lowest basal area.

Table 3.--Average annual crop-tree growth on the Ranger plots for 20 years after thinning

Plot	Reserve basal area	Average annual diameter growth of 160 crop trees per acre
	Sq.ft.	In.
C	92	0.114
A	107	.112
B	116	.112
E	123	.110
D	138	.085
F (check)	145	.086
G (check)	182	.101

Total basal-area growth on the Ranger plots was more closely related to average diameter than to reserve basal area. Plots with the smallest mean d.b.h. tended to show the most basal-area growth.

The Copper Basin plots have a similar history and show similar results. They were thinned uniformly, with crop trees selected later for analysis. As shown in table 4, one thinned plot grew 9 percent and the other 28 percent faster in diameter for 15 years than the unthinned check plot. Diameter growth was again inversely related to the total reserve basal area.

The thinned Copper Basin plots grew more basal area (average 2.5 sq. ft. per acre per year) than the check plot (1.8 sq. ft. per acre per year), suggesting that the check plot was nearing the point of growth stagnation.

Table 4.--Average annual crop-tree growth on the Copper Basin plots, 15-year period following thinning

Plot	Reserve basal area	Average annual diameter growth of 80 crop trees per acre
	Sq.ft.	In.
2	122	0.067
1	156	.057
3 (check)	178	.052

The 16 plots near Redstone on the Gila National Forest are difficult to analyze because of wide variations in sites, exposures, and stand characteristics resulting from locations scattered over 4 sections. There are, however, 4 locations that each have 2 thinned plots. Presumably, two plots at the same location can be compared with a minimum difference in site. Data from the unthinned plots in this series are not used here.

Paired data from these 4 locations are presented in table 5. One pair of plots (9A and 9B) had nearly identical basal area after thinning and the 15-year d.b.h. growth of selected crop trees was almost identical. In the other 3 pairs, 15-year d.b.h. growth of crop trees was 26 to 29 percent better on the plot with less initial basal area.

Basal-area growth on the Redstone plots showed little relationship to reserve stand. Apparently the effects of site and average d.b.h. were more important than those of reserve basal area. The effect of site is suggested by the differences in diameter growth between different locations, shown in table 5.

Table 5.--Growth comparisons in paired thinned plots, Gila National Forest, 15 years after thinning

Plot numbers (paired)	Reserve basal area per acre	Average annual diameter growth of crop trees[1/]
	Sq.ft.	In.
1A	94	0.117
1B	101	.090
4A	112	.149
4B	125	.118
9A	102	.098
9B	104	.101
10A	120	.088
10B	115	.111

1/ Crop trees selected at rate of 80 per acre.

COPPER BASIN PLOT 2

1933 Immediately following first uniform thinning. Residual basal area 122 sq. ft. per acre on 523 trees; Thinning could well have taken one-third of the trees left.

1952 Nineteen years following thinning. Basal area exceeds 160 sq. ft. per acre and should be reduced to 80 sq. ft. in the second thinning.

Thinning in Sapling Stands

There was but little evidence that thinning caused an appreciable increase in height growth of pole-sized stands. By contrast, the two studies in very young stands both showed that thinning increased height growth as well as diameter growth.

The Decker Wash plots were established in 1926 in a 12-year-old stand running as high as 50,000 trees per acre. Only an occasional tree had reached $4\frac{1}{2}$ feet in height: the tallest recorded was 58 inches. A check plot and four thinned plots were established. Thinning was uniform to average spacings of approximately 2, 3, 4, and 10 feet.

In 1948, 22 years after the plots were established, growth was analyzed for the 50 trees on each plot (350 trees per acre) that were tallest in 1926. Results presented in table 6 show diameter growth in relation to degree of release, with increases of 75 to 280 percent resulting from thinning. Spacing of trees 3 or 4 feet apart increased height growth by one-third, but 10-foot spacing gave no advantage in height. Unfortunately, no plots were thinned 6 to 8 feet, which is a more standard spacing in sapling thinning in other types.

The trees that were tallest in 1926 had reached average heights of only 8.6 to 11.6 feet by 1948, when they were 34 years old. The tallest tree on any plot was only 19 feet tall. The site is clearly a poor one for the development of saplings, although part of the slow height growth can be attributed to chronic tip-moth infestation and to competition of large trees around the borders of the plots.

Table 6.--Average annual diameter and height growth, 50 tallest trees per plot, Decker Wash

Treatment (average spacing of trees)	Average annual stump diameter[1/] growth 1931-1948	Average annual height growth, 1926-1948
Ft.	In.	Ft.
Check	0.025	0.195
2	.044	.226
3	.061	.264
4	.076	.258
10	.095	.189

1/ Stump diameter = 1 foot above ground.

The Corey pasture plots provide data on thinning sapling stands on a better site. The plots were established in 1934 in a stand of 1914 origin (same as the Decker Wash plots). At 20 years of age there

were 6,000 to 7,000 stems per acre. Crop trees at a rate of 600 per acre (approximate 8½-foot spacing) were selected for the following treatments:

1. No thinning;
2. Light release -- 2- to 3-foot space cleared around each crop tree not distinctly dominant;
3. Medium release -- 2- to 3-foot space cleared around all crop trees;
4. Heavy release -- thinned to a spacing of about 8 x 8 feet, all noncrop trees removed.

For the 13 years of record, diameter growth was directly related to the degree of thinning. Crop trees on thinned plots grew 32 to 65 percent faster than on the unthinned plot. Thinning also stimulated height growth of crop trees, with increases of 23 to 45 percent over the check plot. Growth rates are shown in table 7.

Table 7.--Average annual crop-tree growth, 1943-1947, on Corey pasture plots

Plot treatment Degree of thinning	Average annual d.b.h. growth of crop trees	Average annual height growth of crop trees
	In.	Ft.
Check	0.124	0.53
Light	.164	.67
Medium	.169	.65
Heavy	.205	.77

Crop trees averaged 9 to 12 feet tall (plot averages) and 1.6 to 2.7 inches d.b.h. at time of release. The study indicates that stands with dominants and codominants of this size will benefit from opening up to at least 8 x 8-foot spacing.

GENERAL ANALYSIS OF ALL DATA

When the data presented in this and earlier papers are considered together, one conclusion stands out clearly and definitely: In every study, diameter growth of crop trees was increased when competition was decreased. Of 39 plots that can be compared, only 2 failed to fit into this pattern completely, and these 2 plots (Ranger plots D and F) are only slightly out of line (see table 3).

With this minor exception, crop trees in the lighter stands grew 10 to 280 percent faster in diameter than those in the heavier, over a period of 10 to 20 years. Since the differences in stand density were often rather small, and thinning was frequently light, it seems reasonable that crop trees in a dense stand could be expected to grow from one-third to one-half faster if well released.

It also appears that proper thinning may improve crop-tree height growth in dense sapling stands. Some of the data suggest a similar response in pole stands, but it is by no means conclusive. However, Mowat (6) reports that thinning ponderosa pine in Oregon improved height growth rather consistently. He shows that accelerated height growth of pole stands usually does not show up until the second decade after release, and suggests that the increase is greater where stagnation is most evident.

Basal-area growth apparently depends more on site and average stand size than on stand density. Small trees naturally add more basal-area growth than larger trees: 1 inch of diameter growth in a 4-inch stand adds 56 percent to the basal area, while 1 inch adds only 26 percent in an 8-inch stand. There is some evidence in the data that the very lightest stands (less than 80 sq. ft. basal area) and the very heaviest (over 160 sq. ft.) grew less basal area, but when site and mean d.b.h. are considered, stands between these figures all grew at about the same basal-area rate.

An interesting comparison of stocking is provided by Lexen's (5) table of ponderosa space requirement. From it the basal area of fully stocked stands on somewhat better than average sites can be calculated. For pole stands it turns out to be $96\frac{1}{2}$ to 98 sq. ft. per acre, and for sawtimber stands, a uniform 98 sq. ft.

When basal-area growth is equal in two stands, individual trees must grow faster in the lighter stand. Average diameter growth will be 22 percent faster in an 80-sq. ft. (basal area) stand than in one of 120 sq. ft. per acre, and 41 percent faster than in one of 160 sq. ft., if all stands have the same average d.b.h. and are growing at the same basal-area rate per acre.

These theoretical figures fit remarkably well with the data from the plots. Records of stands before thinning are incomplete, but of 18 plots on record, 9 had basal areas in excess of 160 sq. ft. per acre before thinning, and only 2 (both check plots) had basal areas less than 120 sq. ft. per acre. Thinning was relatively light: 13 plots with before-and-after records had from 22 to 36 percent of the original basal area removed. Reserve stands were fairly heavy: only 11 out of 29 were under 100 sq. ft. basal area per acre. When all this is considered, the previous conclusion that thinning might improve crop-tree diameter growth by one-third to one-half seems quite logical if a heavy stand (160 to 200 sq. ft. basal area) were reduced by one-half.

Volume growth of potentially usable wood (e.g., to 4-inch d.i.b.) has not been computed for any plots because volume tables have not been available. Actually, such data would have little meaning, because ingrowth into usable size would be so variable between plots. All plots initially had some trees below the 5-inch d.b.h. class (commonly accepted as the lower limit of usability) and the Decker Wash, Corey pasture, and 1 of the Gila plots were entirely or almost entirely below 5 inches d.b.h.

Total volume and volume growth (including all tallied stems to the tip, regardless of size) were computed on the Ranger and Section 19 plots. Results follow those for basal area fairly well, except for greater variability resulting from variability in height. Growth seemed to be more dependent on site, stand diameter, and stand height than on reserve basal area or degree of thinning.

The immediate advantage of thinned stands is that growth is being concentrated on fewer, selected, better quality trees.

The foregoing results are in line with thinning results elsewhere and with other species. The significance of increased crop-tree growth has not been fully developed, however.

VALUE OF SHORTENED ROTATIONS

Thinning will reduce the length of time required for a stand to reach a size suitable for a first commercial cut, as well as rotation age. The magnitude of the growing-time reduction will depend on the nature of the stand and the intensity of the treatments; treatment may in turn be prescribed by current and anticipated markets for forest products, especially subsawlog products. An average sustained diameter-growth increase of one-third on selected crop trees means a reduction of one-fourth in the remaining rotation to a fixed d.b.h. A 50-percent diameter-growth increase will reduce the time by one-third. Data from the study plots therefore suggest that thinning may reduce by one-fourth to one-third the time required to get crop trees to rotation size. The time saved may easily be 30 to 40 years.

It is obvious that there is an economic advantage in concentrating growth of the forest on high-quality trees so that they will be the major part of the crop. The financial advantage of a shortened rotation, aside from quality aspects, is not so well understood.

To illustrate how the advantage of accelerated growth could be expressed in terms of dollars, the following approach is suggested:

Assume that a properly stocked forest will yield a harvest of 22,500 board-feet per acre regardless of the length of rotation, that the rotation can be shortened by 30 years through early thinning, and that the period remaining until actual harvesting will be shortened from 100 years to 70 years. Adopting the standard discount formula, the present discounted value (per $1 of harvested value) of the shortened rotation is:

$$Vs = \frac{1.00}{(1+p)^{70}} - \frac{1.00}{(1+p)^{100}}$$

Computed discounted values at different discount (interest) rates, with extensions to the assumed yield of 22,500 board-feet valued at $10 per M, are:

Discount rate	Present value of shortened rotation	
	Per $1 harvest value	Per acre for total harvest
p	Vs	$225/A at $10/M
2%	$0.1120	$25.20
2½%	.0929	20.90
3%	.0743	16.72
4%	.0444	9.99

This computation shows that the assumed reduction in time of harvest, brought about by thinning, is today worth $16.72 per acre with interest at 3 percent. This is the amount that theoretically could be invested today and eventually be recovered with 3 percent interest.

This example is, of course, oversimplified. It does not consider yields from commercial intermediate cutting, the effect of improved quality, or the possibility of rising stumpage prices. The computation is presented to show that a shortened rotation has a definite current value and to suggest a method of estimating such value.

This analysis has not considered other possible values of thinning in multiple-use management. Thinning provides improved disease control but may create immediate bark beetle problems. The net effect on fire protection is not simple. The thinning operation makes an increased slash hazard for a few years but a thinned stand is probably less susceptible to crowning than a dense thicket. Since the thinned stand will develop faster, it will grow out of the most critical hazard period sooner than an unthinned stand. Also, it is possible that thinned ponderosa pine forests may yield more water and grass.

CROP-TREE VERSUS UNIFORM THINNING

The thinning studies thus far provide little basis for analyzing the relative merits of the crop-tree and uniform methods of thinning. However, since the crop-tree method was developed largely through logical reasoning, it is now appropriate to reexamine the premises and conclusions in light of new data and of changing times.

The change from uniform to crop-tree thinning in 1934 was largely a matter of economy. Pearson (7) cites an example where 30 man-hours of CCC labor were used per acre to thin uniformly a pole-sized stand, plus 10½ hours for pruning all reserve trees. He estimated that 80 crop trees per acre could have been released with 8-3/4 man-hours and pruned with 5 more hours.

Closely related to economy of operation was the premise that a single crop-tree thinning would suffice until the stand could be thinned for saw logs. Released crop trees will have a distinct growth advantage and should maintain dominance over the crowded intervening groups. If not more than 100 to 120 crop trees per acre are selected, these trees will easily reach saw-log size before they start competing with each other, and in the meantime the crowded groups left between would probably be suppressed.

By contrast, uniform thinnings tend to keep an entire stand at a uniform dominance unless deliberately designed otherwise. As the trees grow and their crowns close in, further thinning will be required to maintain adequate stand growth. Uniform thinnings should be done at relatively short intervals. If stands are opened up too drastically, trees will grow too limby and quality will be lost.

Results from the various thinning plots tend to confirm these premises. However, the premises assume no market for material below saw-log size. If 7-inch trees can be used, as appears likely when pulpwood markets develop, the economic objection to uniform thinning disappears for stands of this diameter. In other words, uniform thinnings become practical when stands first reach merchantable size.

Uniform thinnings have one outstanding silvicultural advantage: the best trees are periodically selected for development and the poorest ones are eliminated from the stand. The trees finally harvested, and which will furnish the seed for natural regeneration, are those that have survived a series of selections. Thus the chance of genetic degradation is minimized.

It has been suggested that crop-tree thinning can be used to convert the even-aged stand towards an all-aged condition, by retaining some of the suppressed understory trees as replacements for the crop trees when the latter are harvested. Such a procedure would be genetically questionable if the slower growth of the suppressed trees should be an inherited characteristic, for they would furnish seed for regeneration of areas occupied by the original crop trees.

In practice, then, commercial thinnings -- those where the trees cut have enough stumpage value to pay for the operation -- will ordinarily be done by the uniform method. Where precommercial thinning -- operations where little or no merchantable timber is cut and which therefore require an investment -- is done, the crop-tree method is still very useful because of its lower cost. There is, of course, the possibility that precommercial thinning can be done with heavy equipment, perhaps supplemented with limited hand work, and thus more nearly approach the uniform method at minimum cost. Future thinning studies should include tests of machine thinning.

IDEALIZED STAND MANAGEMENT

It is sometimes helpful to set up an idealized schedule of management, partly as an ultimate goal and partly as a guide in making current management decisions. The data and analyses previously presented suggest that intensive management of young stands might follow the pattern described later. The concepts can be applied to even-aged groups as small as 1/50 acre in a group-selection forest, as well as to extensive even-aged areas.

Ideal management consists of a series of uniform thinnings, the first precommercial when the stand is sapling size, and the others commercial after the stand is large enough to produce cordwood for a market using wood to a minimum 4 inches d.i.b. Each commercial thinning reduces the stand to 80 sq. ft. basal area per acre. Two other assumptions are made for the sake of simplification: that there will be no mortality between thinnings, and that trees removed will be average in d.b.h. for the stand so that thinning will not alter the mean tree size.

Theoretical ideal management is shown diagrammatically in figure 1. Curved lines represent different degrees of stocking, horizontal straight lines represent growth between thinnings, and vertical lines represent thinnings. Various other schedules of thinning could, of course, be shown in the same way.

Management portrayed in figure 1 would consist of the following steps. All figures are per acre.

1. Precommercial thinning in sapling stage when trees selected to be reserved are under 3 inches d.b.h. Reserve 600 trees per acre

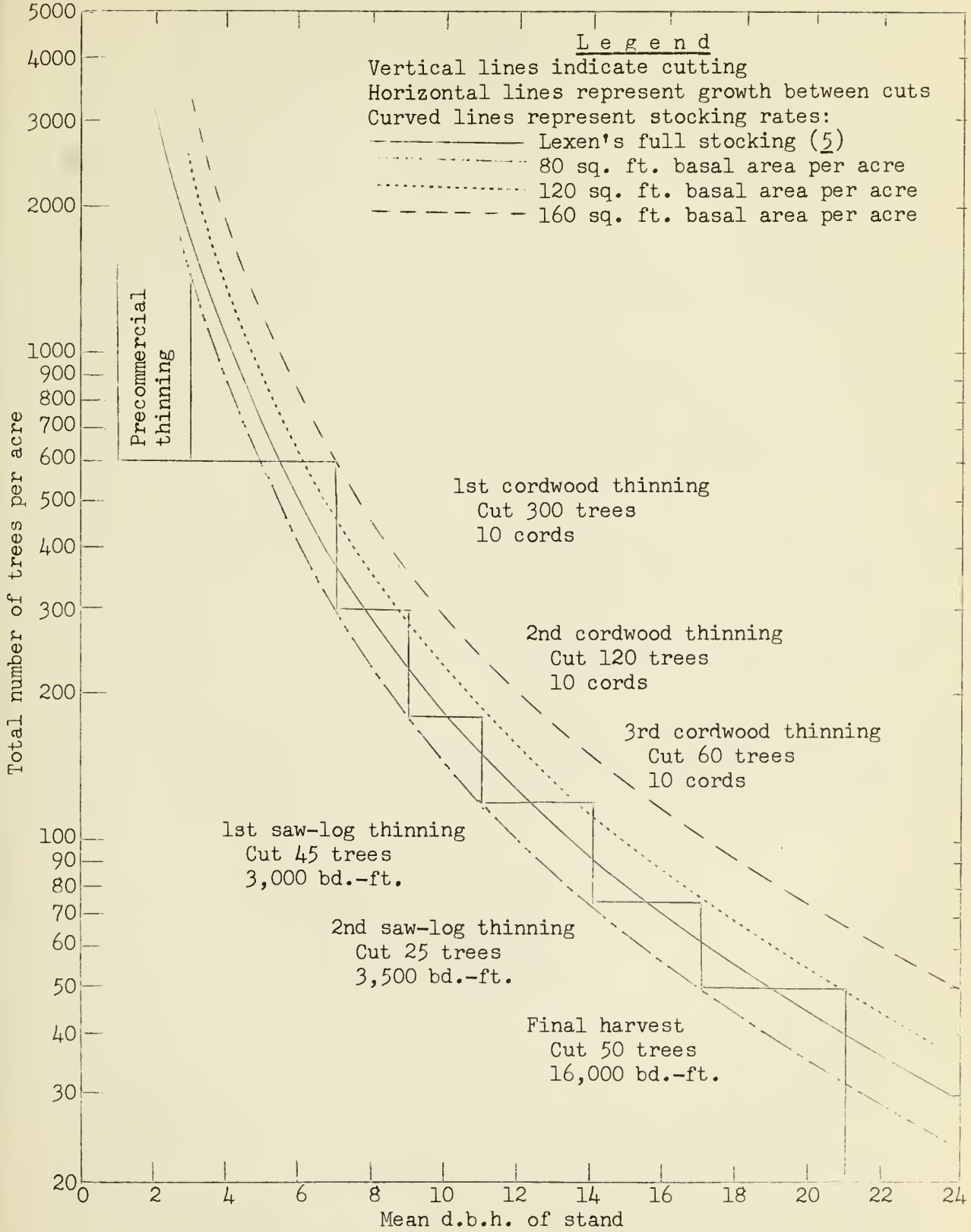

Figure 1.--Graphic demonstration of idealized stand management

and cut all others. (Uniform thinning is assumed to be better silviculturally than crop-tree thinning. Because it is cheaper, crop-tree thinning is suggested for precommercial thinnings in the recommendations that follow.)

2. First cordwood thinning when stand averages 7 inches d.b.h. The 600 trees now total 160 sq. ft. basal area. Half are cut, reducing stand to 300 trees with 80 sq. ft. basal area. Cordwood cut will be about 10 cords. A somewhat earlier cut might be silviculturally desirable but delaying to this stage will insure a commercial cut and will also induce trees to develop good form and potential quality.
3. Second cordwood thinning when stand averages 9 inches d.b.h. The 300 trees have 133 sq. ft. basal area. Cut 120 trees and leave 180 with 80 sq. ft. basal area. About 10 cords of wood should be produced.
4. Third cordwood thinning when stand averages 11 inches d.b.h. The 180 trees have 119 sq. ft. basal area. Cut 60 trees and leave 120 with 79 sq. ft. basal area. Cordwood yield about 10 cords.
5. First saw-log thinning when stand averages 14 inches d.b.h. The 120 trees have 128 sq. ft. basal area. Cut 45 trees and leave 75 with 80 sq. ft. basal area. About 3,000 board-feet (Scribner) will be cut.
6. Second saw-log thinning when stand averages 17 inches d.b.h. The 75 trees have 118 sq. ft. basal area. Cut 25 trees and leave 50 with 79 sq. ft. basal area. Volume cut will be about 3,500 board-feet.
7. Final harvest cut when stand averages 21 inches d.b.h. The final 50 trees now have 120 sq. ft. basal area and scale about 16,000 board-feet.

The total yield during the rotation would thus be about 22,500 board-feet of saw logs and 30 cords of wood. If the rotation age is 150 years the average annual yield would be 150 board-feet plus 0.2 cord. In an even-aged management system cutting as outlined above would be done at about the following ages:

Precommercial thinning --- 20 to 30 years
First cordwood thinning --- 50 years
Second cordwood thinning -- 65 years
Third cordwood thinning --- 80 years
First saw-log thinning ---100 years
Second saw-log thinning ---120 years
Harvest cutting ---150 years

This schedule could undoubtedly be accelerated on the best sites and would have to be slower on poor sites.

Alternative thinning schedules should produce about the same total yields, provided the stand is never reduced below 80 sq. ft. per acre of basal area. Thus, in group-selection management with a 20-year cutting cycle, each group would be thinned back to 80 sq. ft. basal area per acre every 20 years until it was ready for harvest, and at the same intervals mature groups would be harvested. When optimum stocking and normal size-class

mature groups would be harvested. When optimum stocking and normal size-class distribution is reached for the group-selection forest, yield at each 20-year cut would be 3,000 board-feet of saw logs and 4 cords of wood per acre, assuming an annual yield of 150 board-feet plus 0.2 cord. This type operation would also allow salvage of some additional cordwood from tops of trees cut for saw logs.

Idealized management, such as has been described here may never be possible in all parts of the Southwest. Scattered forests in remote areas may remain inaccessible to cordwood markets and thus preclude early commercial thinning. Poorer sites may always be below the economic margin for such intensive management. Delay in securing reproduction after harvest cutting will upset schedules and reduce average yields. On the other hand, if anticipated wood markets develop, intensive management may soon be possible on all the best sites of readily accessible forests.

RECOMMENDATIONS

Selecting Stands to Thin

The questions of where, when, and how to thin should be resolved for each locality through analysis of density and extent of stands, average tree size, differentiation of dominance, site, and accessibility to existing and anticipated markets. In many areas in the Southwest, thinning is not needed. There are extensive areas where stands will make fair development if merely allowed to grow, but such stands could be improved materially by thinning. In other cases stands are deteriorating for lack of treatment. Sometimes needed thinnings cannot be justified at present.

Development of markets for small products, especially those such as pulpwood that are unexacting in quality requirements, will be important in determining standards for thinning. When national and world trends of wood use are considered, it seems reasonable to predict that all the larger, most accessible ponderosa pine areas of the Southwest will have markets for cordwood within 20 years. By the end of the century, markets should be available for most areas that are reasonably accessible.

Stands need thinning if the most desirable, most promising, trees are not developing adequately. The most promising trees are those of good form and with potentially good vigor (vigor may have been reduced by overcrowding). Inadequate development usually means inadequate growth, but may also include mechanical interference. Slow growth usually shows in the crown: if the crown is too short or too thin, growth is slow. If slow growth of potentially desirable trees is due to excessive competition, thinning is needed.

Table 8 is offered as a guide in deciding what sort of thinning, if any, should be done in stands of varying ages and with varying market prospects.

Considerable judgment is required to interpret and apply these guides. The following points, particularly, should be considered:

1. The guides can be applied to small even-aged groups as well as to larger even-aged stands.

Table 8.--Guide to method of thinning

Stand size class and anticipated markets	Recommended method of thinning
A. Immature sawtimber stands, over 120 sq. ft. basal area per acre	Uniform thinning to 80 sq. ft. basal area per acre
B. Pole stands	
1. Cordwood market available: stands over 120 sq. ft. basal area per acre	Uniform thinning to 80 sq. ft. basal area per acre
2. Cordwood market expected within 20 years: stands over 200 sq. ft. basal area per acre	Crop-tree thinning, release 120 trees per acre
3. Cordwood market not expected within 20 years: stands over 160 sq. ft. basal area per acre	Crop-tree thinning, release 120 trees per acre
C. Sapling stands, over 1,200 trees per acre	
1. Cordwood market available, or expected within 20 years	Crop-tree thinning, release 600 trees per acre
2. Cordwood market expected in 20 to 50 years	Crop-tree thinning, release 300 trees per acre
3. Cordwood market not expected within 50 years	Crop-tree thinning, release 150 trees per acre

Spacing equivalents for number of trees per acre

No. trees per acre	Approximate spacing Ft.
120	19 x 19
150	17 x 17
300	12 x 12
600	$8\frac{1}{2}$ x $8\frac{1}{2}$
1,200	6 x 6

2. Generally, stands below the indicated densities will not need thinning. Lighter stands with appreciable numbers of low-quality dominants (wolf trees) may require improvement or liberation cutting.
3. Stands above the indicated densities may not need thinning if there are sufficient good-quality trees that are dominant enough to maintain good growth.
4. Thinning of immature sawtimber groups (stand class A, table 8) in virgin forests may be delayed one cutting cycle to keep the first harvest-salvage cut light and the cycle short.
5. The first uniform commercial thinning in pole stands (class B-1, table 8) will be restricted by the lower merchantable limit of products removed. Some additional, noncommercial, thinning may be desirable to insure that 120 crop trees per acre can develop adequately. In this case, treatment combining parts of B-1 and B-2 may be required.
6. Uniform commercial thinning in stand classes A and B-1 may be done in stands of less than 120 sq. ft. basal area per acre, if commercially feasible. Basal area of desirable trees should not be reduced below 80 sq. ft. per acre.
7. The smaller the average tree size, the cheaper will be a noncommercial thinning. There should be no delay in thinning a sapling stand that obviously will stagnate before it is large enough for a commercial thinning. However, stands should be well established -- crop trees probably at least 6 to 8 feet tall -- before thinning, so that there is some evidence of relative quality and vigor of individual trees.
8. The recommended guides presuppose that a single noncommercial crop-tree thinning will carry the stand until a commercial uniform thinning can be made. This may be too hopeful for sapling stands with no cordwood market expected within 50 years (stand class C-3, table 8). Crop trees may require a second release in this case.
9. Uniform rather than crop-tree method would be preferred silviculturally in areas where a cordwood market is expected within 20 years (classes B-2 and C-1, table 8). The crop-tree method is recommended here only because it is cheaper. There is still the possibility of developing an inexpensive method using heavy equipment or fire in sapling stands.
10. In all cases, the stand will be thinned several times before it reaches maturity. The whole job need not be done the first time.

More detailed recommendations for field application of the two thinning methods, uniform and crop-tree, are presented in the following sections.

Uniform Thinning

It is usually assumed that uniform thinning will tend to keep the treated stand or group even-aged. Actually, the technique can promote a more uneven-aged condition by taking maximum advantage of natural stand variation and by giving some trees more release than others. The following principles can be applied either to maintain an even-aged condition or to

increase variation in the stand. It will be noted that classic thinning concepts do not apply strictly. Selection of reserve trees leans towards the principle of crown thinning, but the release has most of the elements of a class D low thinning.

1. Select trees to reserve as growing stock.--In choosing reserve trees some compromise between spacing and tree quality and thrift is necessary, particularly in the first thinning. Ideally, a thinned stand would be made up of regularly spaced trees of good form and vigor, but in practice slightly inferior trees may be reserved to improve spacing, or spacing may be quite irregular to reserve the most promising trees. Later thinnings will more nearly approach the ideal.

   Uniform thinnings in pole and sawtimber stands should reserve a stand of 80 sq. ft. of basal area per acre. If a uniform thinning is made in a sapling stand in anticipation of an early cordwood thinning, about 600 trees per acre should be reserved, as this many can be carried to 7 inches d.b.h.

   The following rule-of-thumb spacing formula will leave about 80 sq. ft. of basal area per acre:

   S = 1.75D, where

   S is the average spacing between reserve trees in feet, and

   D is the average d.b.h. of reserve trees in inches.

   Other devices are available to aid in estimating basal area, including the Bitterlich instrument described by Grosenbaugh (1) that determines basal area per acre directly. In practice, the timber marker will soon learn to judge spacing so that only occasional checks of basal area are needed.

   If the stand has been thinned earlier by the crop-tree method, the previously selected crop trees will normally be included in the reserve stand if they are still of good thrift and quality.

2. Release the reserve stand.--Theoretically, all nonreserve trees are cut in a uniform thinning. In practice, however, there may be a number of trees that have not yet reached minimum merchantable size. Ordinarily such trees can be left standing, even though the total residual stand then exceeds 80 sq. ft. basal area per acre. They will not compete seriously with the dominant reserve stand and they may develop enough to contribute some volume to a later thinning. Small trees that interfere directly with the development of the main reserve stand should be cut.

3. Prune selected crop trees.--If the stand is sapling or pole size, 100 to 150 per acre of the better reserve trees may be pruned to develop high-grade butt saw logs.

4. Re-treatment.--On average or better sites, pole-sized stands thinned to 80 sq. ft. of basal area will grow to 120 sq. ft. in about 20 years. By this time diameter growth will be slowing down again and another thinning will be needed.

Basal-area growth rate drops as trees become older and larger. In an even-aged forest, it will probably be necessary to lengthen the thinning cycle when the stand gets into sawtimber size. In all-aged forests, each even-aged group would be thinned as needed at each regular cutting cycle.

Crop-tree Thinning

Crop-tree thinning, as developed in the following paragraphs, is a rather crude adaptation of the classic crown-thinning method.

1. Select crop trees to release.--Crop trees should be of good form and vigor, trees that will make best quality wood in the shortest time. Some dominants will qualify but many will be too coarse and limby. The better codominants will often be the best to select.

   Numbers of trees to select under different conditions were recommended in table 8. The corresponding spacings should be followed as closely as possible. Rarely should two crop trees be chosen at closer than half the indicated spacings, and ordinarily individual spacing should be within three-fourths of that indicated.

2. Release the crop trees.--Past recommendations for release of crop trees (9) have apparently not been drastic enough for maximum growth response. While the following suggestions have not been tested in practice, it is believed that they will permit the tree to assume and maintain dominance and a good growth rate.

   All trees interfering mechanically with the development of a selected crop tree should be cut. Most trees of low quality will be cut as a liberation or improvement cutting. Additional cutting depends on the initial crown class of the selected crop tree:

   a. Crop-tree dominant: cut all other dominants whose crowns touch that of the crop tree.
   b. Crop-tree codominant: cut all dominants within half the distance to adjacent crop trees; cut all codominants whose crowns touch that of the crop tree.
   c. Crop-tree intermediate: cut all dominants and codominants within half the distance to adjacent crop trees; cut all intermediates whose crowns touch that of the crop tree.

   Again, personal judgment should enter into the application of these rules. For instance, treatment of a sapling stand should leave enough side shade to stimulate height growth and to prevent development of unduly large limbs. Experience may prove that less drastic treatment and a second release may be necessary in some cases.

3. Prune crop trees.--If an investment in thinning can be justified, pruning is likely to be profitable, too. However, only trees to be grown to saw-log size should be pruned so that in sapling stands thinned in anticipation of a cordwood market only 100 to 150 per acre of the released crop trees should be pruned. Severe pruning of live crown should be avoided lest the benefits of thinning be nullified.

4. Re-treatment.--If possible, a crop-tree thinning should carry the stand to the point where a uniform commercial thinning can be made. However, if a stand first thinned in the sapling or small-pole stage must be carried to sawtimber size for commercial thinning, it may be very desirable to re-release the selected crop trees 20 to 30 years after the original thinning.

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